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Book Lays A Foundation In Control Theory And How To Apply It In Power Converter Design

Designing Control Loops for Linear and Switching Power Supplies: A Tutorial Guide, Christophe Basso, Artech House, ISBN-13:978-1-60807-557-7, glossy hardback, 593 pages, 2012.

*Reviewed by Dennis Feucht, Innovatia Laboratories, Cayo, Belize**

The author of this book is an engineer at ON Semiconductor in Toulouse, France, involved in switching power supply design including integrated circuits. For anyone involved in power supply design nowadays, the subject matter of control is unavoidable. It is also extensive. Many undergraduate EE curricula do not require EE students in the U.S. (or maybe in France either) to take the one-year course in introductory control theory. Consequently, too many EEs involved in switching converter design lack the needed background, and Basso's book fills a gap in addressing control from a converter standpoint. He goes beyond what is typically included on feedback in active-circuits textbooks.

In the first couple of chapters, Basso sets forth the basic principles, beginning with what *is* required in school—passive and active circuit dynamics—and includes feedback dynamics, with poles, zeros, and the complex-frequency (*s*) domain. One of his topics, in passing, shows that he has familiarity in using the math involved. Section 2.1 is "Writing Transfer Functions the Right Way", which means putting them in normalized form so that the constant factor is the quasistatic (low-frequency) gain and all frequencies appear in ratios. He also (pp. 234 to 240) takes apart the arctangent function in more detail than most books, showing how to determine the right polarities for angles of different quadrants.

Another useful section—not necessary for the formal theory but quite helpful in using it—is how to identify circuit poles and zeros by inspection. There is much more to be said on this topic but this section certainly helps those who otherwise would not know where to begin.

Chapter three addresses feedback-loop stability and has more dynamic-circuit-response concepts. Basso also includes an aspect of feedback loops that is not easily found in control theory textbooks, that of the effect on phase margin of delay in the loop. This is a significant topic because switching converter loops are discontinuous in time and some of their behavior is better characterized by delays than by poles (though delays can be approximated by complex pole-and-zero pairs). Throughout the discussion, the familiar tools of the electronics engineer are seen: simulations, frequency-response plots, and of course, a judicious amount of *s*-domain math.

Chapter four follows naturally from chapter three: loop compensation. Basso likes categories of compensators and leading the list is the PID compensator. Although some engineers find these categories useful—and they perhaps can route the non-control engineer around deeper involvement in control theory—I would have preferred thinking about compensation in the simpler form of poles and zeros and their effects on phase margin, as can be (usually) seen on Bode plots, and where their placement would improve phase margin.

Nevertheless, the basic issues and problems are addressed, and one is not the worse off for learning about types 1, 2, and 3 compensation, and about PI and PID compensators. In practice, it is sometimes difficult to add the required compensation to a circuit without modifying the circuit more than is desired. Basso gives circuit examples of compensation.

Chapters 5 through 8 delve more deeply into circuit design, given the control-level requirements on the feedback circuits of a converter. Some of the complications that are addressed are isolation and optocouplers. Some common circuits driving optocouplers are analyzed in detail, as is the popular TL431 voltage reference (ch. 7). Multiple paths in the waveform flows complicate the analysis.

The error amplifiers in switching converter control ICs are given a chapter. These amplifiers need to be understood in some detail and Basso saves the reader much trouble in practice by bringing out details that even the manufacturer's data does not state (or state clearly). Chapter 8 is about another largely-neglected topic, that of *shunt* switching regulators, exemplified in the chapter by the Power Integrations TOPSwitch series.

Chapter 9 covers a somewhat neglected but important topic, of how the input filter can form a resonance (and oscillate spuriously) with the negative input resistance of the converter itself. The incremental (small-signal) input resistance is negative because converters (usually) operate as constant input-power devices. Consequently, if the input voltage of a converter increases, the input current decreases (by reducing the duty

ratio) to keep the input power constant. An increase in voltage causes an increase in current across positive resistances, yet just the opposite happens at the converter input port, and it is modeled as having a negative resistance. This can lead to oscillation. Basso describes the problem and its solutions using waveforms, circuit models, and more Bode plots.

The first part of ch. 9, however, is different and for the bench. How do you measure the various quantities that are theoretically calculated or predicted? The book spends a half chapter on measurement methods, somewhat reminiscent of the methods pioneered by R. D. Middlebrook of Cal Tech but not limited to his methods.

The index of the book is not a token index but should be useful in finding one's way around within its almost 600 pages.

In writing this book, Basso has done a service to the many power-electronics designers who struggle with feedback-loop performance and the control aspect of converters in general. The essential concepts are presented in a quite readable way (and the English is grammatically correct, given that the author is native French; no "Franglish" was found).

Those who are already versed in control theory might prefer other ways of thinking about some aspects of control, yet this book follows through in enough detail with actual examples to see what the author has done in solving the control problems. It is thus useful also to those who know control well but are weak on the particulars of how to apply it to power converters. For that, I can recommend Basso's book as one to keep at arm's reach on your bookshelf. I can foresee numerous engineers reaching for this book when troubled by a circuit problem because it is both circuit-oriented and problem-oriented.

Converter control is a vast subject. One book cannot cover everything. What Basso does not *cover*—at least it is not emphasized—is the analysis and modeling of control methods such as the popular peak-current controller. It has few circuit components but is rather difficult to analyze, involving sampling theory (a topic avoided by the book) and several generations of refined models over the last four decades. (The reviewer is being particular about this because I published a whole series on peak-current control modeling in *How2Power Today* about two years ago.)

To model converters in all the detail that control and DSP theory allows takes one into a different realm than this book covers, a realm that many engineers will not enter. Thus, Basso's book takes the reader about as far as you can go—and it is often far enough—without saying anything about the "unified model" or "Ridley's model" of current controller loops. Basso addresses the sampling issue within the loop by bringing in loop delay and how it influences phase margin. And that might be quite sufficient for many designers.

Yet it should be remembered that after mastering what is in Basso's book, there is more on the subject. And I am presently writing a power-electronics book to try to simplify control modeling. Robert Sheehan of National Semiconductor has also done some additional modeling work as given in his paper "Current-Mode Modeling for Peak, Valley, and Emulated Control Methods", at www.nsc.com under papers.

Meanwhile, get a copy of Basso's book. Future books will not obsolete what is covered in it, and it should stand as a major work on converter control for design engineers for some time to come.

**Editor's Note: The reviewer was one of numerous esteemed individuals who reviewed chapters of Basso's book and provided feedback to the author during the writing of the book. These individuals are identified in the acknowledgements section of Designing Control Loops for Linear and Switching Power Supplies: A Tutorial Guide. However, as Feucht notes, he had no control over how his feedback was or was not implemented and his efforts in reviewing chapters did not impact his efforts in reviewing the finished book for How2Power Today.*

About The Author

Dennis Feucht has been involved in power electronics for 25 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been doing current-loop converter modeling and converter optimization.